NORMAL HUMAN AGING:

The Baltimore Longitudinal Study of Aging

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CHAPTER II

Longitudinal Studies: Past and Present

INTRODUCTION

Although students of growth and development recognized the limitations inherent in cross-sectional studies and the advantages that could be derived from longitudinal studies, the latter were rare before the 1920s. A few classic studies were reported in which height and weight were recorded at frequent intervals in the same children from birth to maturity (Scammon, 1927), but it was not until the 1920s that significant numbers of children were measured repeatedly as they grew and developed (Dearborn et al., 1938; Shuttleworth, 1939; Meredith, 1935). As Chapter I indicates, these early studies provided important insights into growth and development that could not have been derived from cross-sectional observations alone, and thus substantiated the usefulness of longitudinal analyses. Key findings included the discrepancies between growth patterns in individual children and average curves determined cross-sectionally; the estimates of growth rates in individual children; and the relation between growth and specific physiological events, such as maximum growth rates and the initiation of menstruation in girls.

As early as 1947, scientists recognized the necessity of conducting longitudinal studies in adults. The resulting programs (Keys et al., 1961; Dawber et al., 1951) were designed to identify risk factors for the development of cardiovascular diseases (CVD) rather than to describe the phenomenon of aging. Most emphasized physiological functions, and only a few included tests of behavioral or personality characteristics.

During the early 1950s additional longitudinal studies in adults were initiated. In some the goal was to study age changes in specific functions, such as the electroencephalogram (EEG) (Busse and Obrist, 1970) or mental performance (Owens, 1953, 1966; Schaie and Labouvie-Vief, 1974) rather than to identify risk factors for disease. Although these studies focused on aging as a primary variable, only a few made observations on both behavioral and physiological characteristics in the same subjects. Moreover, the number of subjects tested was often small. While most of the studies were purportedly based on "normal" subjects, evidence for "normality" or the absence of specific diseases was seldom adequate. In many studies, self-reports of health status were used: Subjects who said they felt well were regarded as healthy. In studies that assessed health status by a clinical history and physical examination, there were such wide differences in the scope of the examinations that it was difficult to compare the health status of subjects in different studies.

The duration of these studies varied from three to ten years, during which only three or four sets of observations were carried out. None of the studies attempted to calculate age regressions for individual subjects.

Most of the previous studies were terminated before long-term consequences of early events could be evaluated. In some studies observations were limited to subjects aged 65 or older; in others most of the subjects were younger than 25 years at the original testing.

The diversity of populations selected for study, the spectrum of tests, the different

testing intervals, and the duration of the various studies were taken into consideration in the design of the Baltimore Longitudinal Study of Aging (BLSA) (see Chapter III). The present chapter, which provides a brief overview of the major longitudinal studies of aging in adults, is intended to supply the background that influenced the design of the BLSA at its initiation and during its subsequent development.

STUDIES OF GROWTH AND DEVELOPMENT

Since about 1920, a number of longitudinal studies have focused primarily on the physical and mental growth of children. Some, such as the Harvard Growth Study (Shuttleworth, 1937, 1939), were concerned primarily with physical growth as it is manifest in anthropometric data. Others that dealt only with tests of intellectual and personality development include the Terman-Stanford study of gifted children (Terman and Oden, 1947, 1959; Oden, 1968). In a few, such as the Denver study (Lewis et al., 1943) and the Oakland Growth Study (Shock, 1946), measurements of a number of physiological functions as well as intellectual, personality, and social characteristics were also made on the same children as they grew and developed. A few, among them the Terman-Stanford study (Terman and Oden, 1947, 1959; Bayley and Oden, 1955; Oden, 1968) as well as the Oakland Growth Study and the Berkeley study (Jones et al., 1971), continued observations into the adult years (Eichorn et al., 1981). Their subjects, many of whom were 50 to 60 years of age in 1978, represent a potential resource for studies of aging if they can be identified and systematically retested.

STUDIES OF SELECTED POPULATIONS OF ADULTS

1. The Cardiovascular Disease (CVD) Project at the University of Minnesota

One of the first studies of adults specifically designed to be longitudinal was initiated in 1947 under the leadership of Dr. Ancel Keys at the University of Minnesota Laboratory of Physiological Hygiene. A total of 281 business and professional men from Minneapolis and St. Paul were recruited for the study, which was "aimed at providing clues about etiology and evaluating the prognostic significance for future heart disease risk of characteristics observed in health" (Keys et al., 1961). The subjects, aged 45 to 54 years in 1947, spent one day each year at the laboratory for an examination which included a review of the interim history, physical examination, nude weight, chest roentgenogram, 12-lead electrocardiogram (ECG), urinalysis, and measurement of hemoglobin and serum cholesterol, as well as special tests that varied from year to year. These included cardiovascular responses to physical exercise, the cold pressor test,[1] cardiovascular responses to passive tilting, ballistocardiogram,[2] EEG, flicker-fusion frequency,[3] basal metabolism, body density, subcutane-

[1]The rise in blood pressure following the immersion of one arm (or foot and leg) in ice water.

[2]A measurement related to the amount of blood ejected by the heart at each beat.

[3]The frequency of a flashing light perceived as a continuous stimulus.

ous fatness, sugar, uric acid and protein-bound iodine in the blood, anthropometry, and evaluations of personality, based primarily on scores on the Minnesota Multiphasic Personality Inventory (MMPI). Only a part of these longitudinal observations have been published. Leon and her colleagues (1979) reported stability coefficients for the MMPI ranging from .277 (scale 8) to .736 (scale 0) in a sample of 71 men measured at middle age in 1947 and then again 30 years later. In addition, the general profile configuration and two-point code types remained remarkably stable and within normal limits over the 30 years from middle to old age.

During the first 15 years of the study (1947–1962), 32 deaths occurred (Keys et al., 1963). Although not all the data have been reported, the study was able to show that elevated serum cholesterol at the first examination and increased systolic blood pressure in the last pre-disease year were significant predictors of the development of coronary artery disease (CAD) and death. Average data over all pre-disease years showed significantly reduced risk among the men in the bottom quartile for diastolic as well as systolic blood pressure, while elevated blood-cholesterol levels were significantly prognostic for the development of CAD.

Keys et al. (1971) reported results in the same group of subjects over a 20-year interval. In 1968, 168 of the 221 living subjects were examined; in 1969, 151 out of 215; in 1970, 153 out of 212. As of 1970, nine of the original 281 subjects had been lost to follow-up, although some of the subjects who were located failed to come to the laboratory to be retested. Information about the health status of the subjects (aged 67–77 in 1970) was obtained periodically from correspondence with the men (49 living outside the state of Minnesota), from their wives, from their personal physicians, or from all three. Of the 60 men who had developed CAD, 42 died or suffered cardiac infarction. Among 20 variables studied, hyper-responsiveness on the cold pressor test, a high level of serum cholesterol, and elevated systolic blood pressure had significant predictive power for cardiac infarction or death from CAD, while smoking and relative body weight (actual weight expressed as a percentage of "standard" weight for sex, age, and height[4]) seemed unimportant as predictors, especially in subjects over age 65.

Analysis of serial measurements of basal metabolism showed that the rate of decrease with advancing age is substantially less than that inferred from cross-sectional studies (Keys et al., 1973).

The availability of longitudinal observations permitted an evaluation of the changes in body weight after cessation of cigarette smoking (Brozek and Keys, 1957). The subjects were men who voluntarily stopped smoking cigarettes; their body weight was measured for two years before and three years after they stopped. A control group of men who continued smoking were matched in age, relative body weight, and actual body weight at the beginning of the first year of the five-year period, without reference to weight trends during the rest of the period. There was no significant difference during the two periods in the body weights of the men who continued to smoke, while those who stopped smoking gained, on the average, 8.2 pounds over the three years following the date they stopped.

There is also a brief report of a 30-year follow-up of these subjects. Obesity, as assessed by the Body Mass Index (wt/ht^2), was not significantly predictive of overall mortality or of death from CAD (Keys, 1980).

[4]"Standard weight," based on height, was derived from tables published by the Metropolitan Life Insurance Company (1959).

Table II.1. Duke Study. I. Longitudinal Observations: Summary of Variables

- Medical history (original and interim)
- Physical examination
- Neurological examination
- Mental status
- Depression and hypochondriasis
- Dermatological examination
- Ophthalmological examination
  - Visual fields
  - Acuity
  - Color perception
  - Depth perception
  - Color photographs
- Audiometry
  - Pure tone
  - Speech threshold
- Electroencephalogram
- Electrocardiogram
- Chest x-ray
- Laboratory studies
  - Urinalysis
  - Blood morphology
  - Blood chemistry
  - Serologic test for syphilis
  - Cholesterol
  - Urea nitrogen
  - Immunology
- Medical data
- Psychological data
  - Rorschach
  - Aspiration level (TAT)
  - Wechsler Adult Intelligence Scale
  - Reaction time
- Social history and information
- Retirement data
  - Activities
  - Attitudes
- Longevity

From Busse and Maddox (1980)

2. The Duke Studies

Two longitudinal studies have been carried out at Duke University. The goal of the first, initiated in 1955 under the leadership of Dr. E.W. Busse, was to provide answers to two questions: "What are the basic physical, mental, and social processes of normal aging?" and "What accounts for the variations in these processes?" (Busse, 1970). The study was based on 267 men and women, aged 60 to 90 years ($\bar{x}$ age = 70.8 yr), residing in the community. Each panelist was admitted to the Medical Center for a two-day series of medical, psychiatric, psychological, and sociological examinations. These examinations were repeated every two to four years until 1965, and then every two years until 1972. In 1973, the eighth series of tests was completed on the 64 survivors of the original cohort ($\bar{x}$ age = 82.3 yr). In 1976, the 11th series of tests was conducted on 43 survivors ($\bar{x}$ age = 85.2 yr). The tests administered are summarized in Table 1 (Busse and Maddox, 1980). *Normal Aging*, edited by Dr. E. Palmore (1970), reprinted 49 articles by 31 authors based on a variety of analyses of data collected in this panel of subjects.

The results of the first Duke study emphasized the advantages of longitudinal and multidisciplinary studies. The longitudinal analysis made possible the discovery of a general persistence in activities and stability in such traits as hypochondriasis and denial of illness. The inference of failing functions drawn from averages based on cross-sectional data was contradicted by the longitudinal studies, which identified a substantial number of subjects who showed no decline in health status or intellectual function over a number of years; many actually showed improvement in health status (Maddox and Douglass, 1973). Even those who showed substantial impairment of physical functioning, EEG abnormalities, CVD, or impairments in vision and hearing often remained functioning residents of the community, living fairly mobile and independent lives. The surprising degree to which self-perceptions of health vary among individuals constituted a major finding (Maddox and Douglass, 1974).

Table II.2A. Duke Study. II. Adaptation Study Design

Independent Variables (Resources)		Dependent Variables (Measures of Adaptation)	
A.	Physical Medical history Physician's ratings ECG and laboratory tests	A.	Performance Financial and social independence Productivity and social activity Reaction time and accuracy
B.	Psychological Intelligence Personality Vigilance function	B.	Intrapsychic Happiness-depression Psychosomatic symptoms Self-concepts
C.	Social Role and activity measures Socioeconomic status Self-concept Health attitudes Social attitudes		

From Palmore (1974b)

The second longitudinal study, designated "The Duke Adaptation Study," was initiated in 1968. Its goal was to identify the immediate and long-term effects on normal individuals living in the community of such potentially stressful events as death of spouse, serious illness, menopause, children leaving home, preparation for retirement, and retirement, as well as to explore the factors or mechanisms that contribute to "successful" aging defined in a variety of ways (Palmore, 1974a,b). The sample consisted of 261 men and 241 women, aged 45 to 70 years, selected at random from the participants in a major health-insurance plan in the Durham area. The panel was fairly representative of the middle and upper socioeconomic groups in the population. Subjects returned to the center for two days of testing at two-year intervals between 1968 and 1976.

Table 2A shows the design of the Adaptation Study. Table 2B lists the tests administered. Four cycles of testing were completed between 1968 and 1976. Initially, 502 subjects were tested between August 1968 and April 1970. A total of 443 subjects were re-examined by March 1972, 386 were examined for the third time in 1974, and the fourth and final examination was completed in June 1976 on 375 subjects.

In 1974, *Normal Aging II* was published (Palmore, 1974a). Of the 31 articles, 18 are reprints of material previously published in scientific journals, 11 represent new material not previously published, and two are full papers based on presentations made at scientific meetings. Most of the articles deal with results obtained in the first Duke

Table II.2B. Duke Study. II. Summary of Variables

Independent Variables (Resources)	Dependent Variables (Measures of Adaptation)
Medical history	Performance
Physical examination	Financial independence
Audiometry	Social independence
Electrocardiogram	Reaction time and accuracy
Chest x-ray	Physical function
Laboratory studies	Intrapsychic
Urinalysis	Life satisfaction
Blood analysis	Happiness
Immunology	Psychosomatic symptoms
Medical summaries	Self-concepts
Psychological data	Mental status
Intelligence	
Personality	
Continuous performance	
Mental status	
Social history and information	
Role and activity	
Socioeconomic status	
Self-concepts	
Health attitudes	
Social attitudes	
Drug-proneness	
Retirement	

From Busse and Maddox (1980)

Longitudinal Study of Aging. Although more details were added from the analysis of additional data, the general conclusions of *Normal Aging* (Palmore, 1970) were not substantially altered. Adult personality showed little change over the eight years of the study.

A more detailed summary of findings of both studies appears in *Final Report: The Duke Longitudinal Studies* and *The Duke Longitudinal Studies on Aging and the Aged* (Busse and Maddox, 1980; 1983).

3. Normative Aging Study

In 1963, the Normative Aging Study began at the Veterans' Administration Outpatient Clinic in Boston under the direction of Drs. B. Bell, C.L. Rose, and Albert Damon. Studies conducted between 1958 and 1963 in a group of 150 ambulatory octogenarian veterans of the Spanish-American War had made it apparent to the investigators that the identification of special characteristics predictive of healthy old age was not possible simply through the study of older individuals but would require serial studies of a group of younger individuals as they aged (Bell et al., 1966, 1972). The goal was to identify the factors that contribute to health in old age by describing the changes that occur with aging.

The subjects, 2032 males, mostly veterans aged 25 to 75 years, living in the Boston area, included representatives of many ethnic, socioeconomic, and occupational groups in the Boston population (Rose, 1965). All were screened for a high level of health at the time they entered the study; subjects with blood pressure higher than 140/90 mm Hg, for example, were excluded. Another selection factor was the

Table II.3. Normative Aging Study (Boston VA Outpatient Clinic)

Tests Administered	
Clinical evaluation	Anthropometry
Electrocardiogram	
History and physical exam	
Chest x-ray	Blood chemistry
Pulmonary function	Pepsinogen
	Triglycerides
Vision	Protein electrophoresis
Visual acuity	Plasma testosterone
Tonometry	
Dark adaptation	
Dynamic, static, and flicker perimetry	Dental evaluation
Glare sensitivity	Salivary steroids
Turbidity of the ocular media	
Depth perception	
	Thyroid function
Perception	Liver function
Smell	Personality tests
Taste	Intellectual function
Audiometry	Social Information Questionnaire

probability that the subject would remain in the Boston area for his entire lifetime (Rose and Bell, 1965). Although the precise limiting values for exclusion from the study have not been published, the criteria were described as "abnormal values" for pulmonary function, blood-sugar levels, chest x-rays, and ECG. Only four of each ten applicants were accepted after the first clinical evaluation. Subjects came to the laboratory for three nonconsecutive half-days during a five-year cycle. First-cycle tests were administered to approximately 2000 subjects over the period from 1963 to 1968; subsequent cycles were intended to cover the periods from 1969 to 1973 (Cycle II) and from 1974 to 1978 (Cycle III).

The tests included the domains of biochemistry, clinical medicine, oral medicine, neurology, the special senses, anthropometry, psychology, and sociology (Tab. 3). The clinical medicine and biochemistry domains comprised a history, physical examination, standard blood and urine tests, and tests of liver function, serum pepsinogen, triglycerides, plasma-protein electrophoresis, blood sugar, blood-urea nitrogen, uric acid, Ca, P, and protein-bound iodine in the blood. An extensive series of anthropometric measurements was also included, along with resting ECG and blood pressure. ABO blood groupings, lipoprotein phenotyping, and tests for the development of osteoporosis, including a dietary and special medical history and x-rays of the hands, as well as exercise-tolerance ECG, have been added. Smoking histories are obtained for all subjects.

Observations classified as "oral medicine" include orofacial examinations, mastication, a dental survey, facial bone measurements, and parotid saliva secretion rates.

Visual acuity, stereopsis, peripheral retinal shrinkage, dark adaptation, and glare and retinal sensitivity were measured on a subsample of 200 subjects.

Audiologic studies have included sensitivity to frequency and amplitude differences. Tests of retention of verbal and pictorial material, as well as of decision-making under simple and complex classification rules, have been administered to a subsample of the population (Bell et al., 1972).

Selected subjects have been recalled to the laboratory at other times to participate in special tests of such functions as intellectual performance and vision.

Most of the publications from this study represent cross-sectional analyses based on measurements completed during the first cycle of examinations. Burney and Bonus (1972) summarized the clinical laboratory data; Fozard et al. (1972) analyzed the age differences observed in 12 cognitive-performance tests. Dawber and Thomas (1972) presented data originating from clinical examinations of some 1800 subjects, with special emphasis on the frequency distribution of blood-pressure measurements. Clinical data on oral health (Kapur et al., 1972), retinal fields, and pulmonary function (Bell, 1972a) have also been reported for subsamples of the population.

Both Bell (1972b) and Nuttall (1972) presented theoretical approaches to determination of what they called "functional" ages for different types of performance. The approach was to predict chronological age from regression equations derived from specific cross-sectional data sets. For example, Fozard (1972) derived a regression equation to predict chronological age from scores on the General Aptitude test or from the 16 Personality Factor (16 PF) questionnaire. Functional ages were calculated for the domains of blood chemistry, anthropometry, personality, human abilities, sociology, and hearing (Nuttall, 1972) from regression equations derived from experimental data within each domain. The assumption was that meaningful comparisons could be made between the functional ages calculated from observations in different domains. The error of estimate was often large—e.g., 7.2 years for the prediction of age from scores on the General Aptitude test (Fozard, 1972). The usefulness of the concept of "functional age" in contrast to chronological age has been questioned (Costa and McCrae, 1980d).

With completion of the second cycle of testing, analyses were made of the differences in measurements over a five-year interval. Friedlaender et al. (1977) showed that most of the age trends in anthropometry that had been observed in a cross-sectional analysis (Damon et al., 1972) were due not simply to aging but to a combination of aging and birth-cohort effects. *Costa and McCrae (1980a),* who also analyzed anthropometric findings after a five-year interval, were unable to find evidence of a general aging factor. Age trends, when present, varied so much among individuals that no single trend could be identified.

4. The 1000-Aviator Study, Pensacola

In 1940, a study to determine the value of psychological and physiological tests in predicting success in the flight-training program was initiated at the United States Naval Aviation Center at Pensacola, Florida, by Dr. Ashton Graybiel. An extensive battery of physiological, psychomotor, and psychological tests was administered to selected cadets and officers who entered flight training between July 1940 and May 1941. A total of 1056 subjects, aged 20 to 30 years, were tested. All were preselected, in that they entered the study with supine blood pressure lower than 132/86 mm Hg, and had qualified for flight training by passing rigorous medical and flight-proficiency examinations (Oberman et al., 1965a,b; 1967).

It was not until 1951 that retesting survivors of the original cohort was considered. The study was designed to estimate the current physical status of the men, with particular emphasis on the cardiovascular system, morbidity and mortality rates, and the influence of aviation on these rates. In 1951, 703 of the 829 survivors were re-examined. Survivors were also re-examined in 1957–1958, 1963–1964, 1969–1970,

Table II.4 The 1000-Aviator Study

	Time of Testing					
	1940-41[e]	1951[e]	1957-58[e]	1963-64[e]	1969-70[f]	1977[g]
Mean age	23.6	34.6	41.6	48.6	55.6	63.6
Located	1056[a]	1049	836	811	738	728
Survivors		829	816	794		
Re-examined		703	785	675	675	128
Questionnaires only		115	19	89	43	554
No response		11	12	30		
Died		220[b]	20	17[c]	20	46
Not located		7	3	4		
No contact[d]					61	51

[a] Original sample.
[b] 213 men died in World War II.
[c] 5 men died after returning the questionnaire and were not examined.
[d] No information given on survivorship in the "no-contact" group.
[e] From Oberman et al. (1965a,b)
[f] From MacIntyre et al. (1979)
[g] From MacIntyre (1978)

and 1977 (Oberman et al., 1965a,b; MacIntyre, 1978; MacIntyre et al., 1979). The number of subjects tested at each examination is shown in Table 4. Not all the tests used at the first examination were repeated; Table 5 lists the tests administered at each cycle of the study (Mitchell, 1976).

The blood-pressure and ECG data have been analyzed longitudinally. Although the mean blood pressure for the group showed some increase between the initial examination in 1940–1941 and the re-examination in 1963–1964, blood pressure did not increase with age in every subject; in fact, most of the subjects showed random variations in blood pressure over the first 24 years of follow-up. In this relatively young sample, the average increase was the result of a consistent rise in pressure in a relatively small number of subjects. These, it should be noted, also exhibited greater increments in body weight as they grew older, and had shorter-lived parents (Oberman et al., 1967).

Longitudinal analysis of resting ECG (Harlan et al., 1965) indicated that, of 90 men taken into flight training in 1940 whose ECGs would today be considered as indicating frank or borderline abnormalities, 59 had by 1952 reverted to normal. Of individuals in whom ECG abnormalities persisted, none had developed clinically apparent heart disease at the 1963–1964 examinations.

In 1977, a 37-year follow-up of longevity of the 800 survivors was conducted (MacIntyre et al., 1978). The average age of the group was then 60 years. A mailed questionnaire ascertained the subjects' current health status, presence of significant cardiac problems, current jobs, exercise status, amounts of alcohol and tobacco used, and current weight. A markedly lower death rate than would be expected from a random sample of white American men over a similar period was observed. Lower-than-expected death rates occurred in all three major categories of cause of death: CVD, neoplasms, and accidents.

Table II.5. The 1000-Aviator Study: Summary of Tests Administered[a]

Tests	Time of Testing				
	1940-41	1951	1957-58	1963-64	1969-70
Interview — personal and medical histories	*	*	*	*	*
Physical examination		*	*	*	*
Cardiovascular					
Blood pressure (casual, supine)	*	*	*	*	*
Routine electrocardiogram	*	*	*	*	*
Exercise electrocardiogram			*	*	*
Ballistocardiogram			*[b]	*	*
Vectorcardiogram				*	*
Cold pressor test	*		*[b]		*
Other	*			*	*
Laboratory determinations[c]			*	*	*
Pulmonary and metabolic					
Spirometry	*			*	
Other	*			*	*
Anthropometry					
Somatotype	*			*	
Measurements (in addition to height and weight)				*	*
Teleoroentgenograms		*	*	*	*
Psychologic-psychomotor					
Ataxia test	*			*	*
Tilt chair	*			*	
Other	*			*	
Vision	*			*	*
Neurophysiologic					
Electroencephalogram	*			*	
Audiometry				*	*

[a] Completion of the test is noted by an asterisk (*); if a procedure was not performed during an evaluation, the appropriate column is blank.

[b] Examinations performed on less than 25% of the study group.

[c] Laboratory tests included chest x-ray, lipoproteins, cholesterol, triglycerides, uric acid, glucose, hematocrit, WBC including differential, urinalyses (protein, glucose, microscopic).

From Mitchell (1976)

5. The National Institute of Mental Health Study

In 1955, an extensive multidisciplinary study of aging was initiated at the National Institute of Mental Health under the leadership of Dr. J.E. Birren. The purpose of the study was to examine a broad spectrum of variables in individuals of advanced age in whom disease was absent or minimal. The original focus of the study was on the relations among cerebral physiological changes of advancing age, psychological capacities, and psychiatric symptoms. As the study progressed during its initial five years of operation, social-psychological aspects of old age were added. The resulting

study combined the efforts of 22 investigators. The findings of the first study are reported in detail in *Human Aging* (Birren et al., 1963).

The subjects were 47 male volunteers aged from 65 to 91 years (median age = 71 yr) who were living in the community. All subjects were reported to be healthy on the basis of a detailed medical examination. Subjects were admitted to the Clinical Center of the National Institutes of Health for a period of two weeks, during which an extensive battery of physiological and psychological tests was administered (Granick and Patterson, 1971).

In 1961, 29 of the 39 survivors were re-examined at the Clinical Center, Bethesda. Although no comprehensive report of the follow-up has been published, some aspects of the work were reported by Butler (1967), Botwinick and Birren (1965), and Birren (1964). The interviews and tests administered are shown in Table 6. The general

Table II.6. The National Institute of Mental Health Study: Interviews and Tests Administered

Examination or Test	Period of Study		
	1956	1961	1967
Medicine and physiology			
Medical history	*	*	*
Physical examination with complete neurological	*	*	*
Hematology	*	*	*
Blood chemistry	*	*	*
Urinalysis	*	*	*
Chest x-ray	*	*	*
Skull x-ray	*	*	*
Electrocardiogram	*	*	*
Electroencephalogram	*	*	*
Pulmonary-function studies	*	*	*
Cerebral-blood-flow studies	*	*	*
Audiometric examination	*		*
Click-perception tests	*		
Delayed auditory feedback tests	*		
Psychological			
Addition rate	*	*	*
Arithmetic alternation rate	*	*	*
Draw-a-Person	*	*	*
Emotional projection test	*		
Family scene	*		*
Homonyms	*	*	
Learning	*		
Level of aspiration	*	*	
Minnesota Multiphasic Personality Inventory	*		
Mirror tracing	*		
Perception of line diffrence	*	*	
Raven Progressive Matrices	*	*	*
Reaction time	*	*	
Rorschach	*	*	
Sentence-completion test	*		*
Speed of card sorting	*	*	
Speed of copying digits	*	*	*
Speed of copying words	*		*
Stroop Test	*		*
Thematic Apperception Test	*		
Wechsler Adult Intelligence Scale	*	*	*
Weigl Color Sorting	*	*	
Wisconsin Card Sorting	*	*	
Word fluency	*		

Table II.6. The National Institute of Mental Health Study: Interviews and Tests Administered—*(Cont'd.)*

Examination or Test	Period of Study		
	1956	1961	1967
Social-psychological interview			
Family history (or interval history)	*		*
Educational history	*		
Occupational history	*		
Retirement planning and activities	*	*	*
Marital history	*	*	*
Living arrangements	*	*	*
Use of time	*	*	*
Social relations and interaction	*	*	*
Attitudes toward life	*	*	*
Goals and aspirations	*	*	*
Critical turning points in life	*	*	*
Significant losses	*	*	*
Observed physical and mental changes in aging	*	*	*
Psychiatric interviews			
History of psychiatric contact	*	*	*
Personal-social history (or interval history)	*	*	*
Psychiatric-symptom check list	*	*	*
Mental-status evaluation	*		*
Assessment of attitudes about:			
futurity	*	*	*
death	*	*	*
self	*	*	*
aging	*	*	*

From Granick and Patterson (1971)

results indicated little change in the subjects tested after the five-year interval (Butler, 1967), except in tasks such as card-sorting (Botwinick and Birren, 1965) in which speed of performance was the criterion.

In 1967–1968, 19 survivors from the original group of 47 were tested for the third time by other investigators at the Philadelphia Geriatric Center; findings were reported in *Human Aging II* (Granick and Patterson, 1971). Twenty-four of the subjects had died, and four had dropped out. Not all subjects participated in all the tests; for example, cerebral blood flow was measured in only eight subjects.

Every attempt was made to replicate the methods used in the first testing, and many of the investigators who had taken part in the first testing participated in the analysis of the data. Longitudinal results are summarized in Table 7 (Granick and Patterson, 1971). Table 8 lists the variables that at the initial testing had shown differences between subjects who survived and non-survivors.

Although the number of subjects was small, this study showed that decrements in intellectual performance with advancing age were significantly greater in subjects who also developed CVD than in subjects who remained healthy.

6. The Basel, Switzerland, Study

The Basel study, organized by Drs. F. Verzar and O.R. Gsell, was based on measurements made at one- or two-year intervals over a ten-year period (1955-1965) in 121 male subjects aged from 8 to 85 years. Most of the subjects were aged 26 to 56 years at the beginning of the study (1955) and were employees of the CIBA

Table II.7. The National Institute of Mental Health Study: Changes in Survivors after 11 years

Study Area	Type and Direction of Change
Medicine	Almost half had significant diseases. Erythrocyte sedimentation rate increased in healthy subjects.
Cerebral physiology Circulation	Cerebral blood flow decreased.
Electroencephalogram	8 subjects showed some type of EEG change. No systematic changes in the group, but 5 subjects showed slowing of the dominant occipital rhythm. Changes found in all 4 cases of chronic brain syndrome.
Psychology	Vocabulary improved. Picture arrangement improved. Speed of addition declined. Speed of arithmetic alternation declined. Speed of copying words declined. Quality of Draw-a-Person declined. Quality of sentence completions declined.
Psychiatry	Trend toward more organic mental changes. Self-monitoring of intellectual and physical capacities more prominent. "Energy" decreased (self-reports). Sexual interest declined.
Social psychology	Losses in social environment increased. Vulnerability to failure at coping with stressful events increased. "Energy" decreased (self-reports).

From Granick and Patterson (1971)

Pharmaceutical Company (Verzar, 1967; Tripod, 1967). The measurements included anthropometry—height, weight, and circumferences of abdomen, throat, and wrist—vital capacity, maximum expiratory volume, ECG, systolic and diastolic blood pressure, pulse-wave velocity, range of accommodation of the eye, and state of health (Gsell, 1967, 1973). Longitudinal analysis of the data was accomplished by a) calculation of average values obtained from this group of subjects as they aged; b) presentation of curves based on serial measurements on the same subject; and c) calculation of average changes over the ten-year interval. The number of subjects on whom data were available for the full ten years varied from 72 (health evaluation, anthropometry, blood pressure, ECG) to 17 (vital capacity).

Brückner (1967) found that the longitudinal analysis of individual changes with aging in the range of accommodation of the eye showed a more rapid decrease with age than that predicted from cross-sectional studies. Similar differences between cross-sectional and longitudinal analyses were reported by Monnier (1967) for the age-related increase in pulse-wave velocity, which was attributed to the development of arteriosclerosis in major blood vessels. The increase with age shown in 27 subjects for whom serial observations were available over the ten-year period was greater than that shown by the average cross-sectional curve.

Table II.8. The National Institute of Mental Health Study: Significant Differences between Survivors and Nonsurvivors (Initial Measurements)

Study	Factor	Direction for Survivors
Medicine	Health status (groups I and II)	Healthier
	Systolic blood pressure	Lower
	Diastolic blood pressure	Lower
	Mean arterial blood pressure	Lower
	Weight	Heavier
	Arteriosclerosis	Less
	Chronic cigarette smoking	Less
	Serum cholesterol in those who died from coronary heart disease	Lower
	Serum albumin in those who died from carcinoma	Higher
Cerebral physiology		
Circulation	None	
Electroencephalogram	None, but a tendency shown with respect to:	
	Peak occipital frequency	Higher
	Percentage fast activity	Lower
Psychology		
Intellectual and psychomotor	WAIS Verbal scale	Higher
	WAIS Performance scale	Higher
	WAIS subtests:	
	Vocabulary	Higher
	Information	Higher
	Comprehension	Higher
	Similarities	Higher
	Digit symbol substitution	Higher
	Block design	Higher
	Speed of copying digits	Higher
	Speed of copying words	Higher
	Principal Component I (stored information)	Higher
Personality	Draw-a-Person	Higher
	Rorschach	Higher
	Homonyms	Higher
	MMPI-Si scale (social involvement)	Higher
Psychiatry	Adaptation	Better
	Mental status	Higher
Social psychology	Organization of behavior	Higher
	Environment loss	Lower

From Granick and Patterson (1971)

The Basel study provides evidence that the following age differences, identified in cross-sectional studies, represent age changes that occur in individuals (Gsell, 1967): rise in blood pressure, increase in obesity, decrease in vital capacity, decrease in range of accommodation of the eye, increase of pulse-wave velocity, and increase of abdominal and chest circumference.

Table II.9. The Bonn Longitudinal Study of Aging: Number of Participants and Dropouts and Number of Control-Group Participants

	Measurement Point					Control
	I	II	III	IV	V	
Younger cohort						
Men	59 (4)[a]	55 (8)	47 (7)	40 (4)	36	13
Women	55 (5)	50 (2)	48 (10)	38 (7)	31	22
Sum	114 (9)	105 (10)	95 (17)	78 (11)	67	35
Older cohort						
Men	59 (7)	52 (3)	49 (10)	39 (11)	28	13
Women	49 (4)	45 (5)	40 (11)	29 (3)	26	13
Sum	108 (11)	97 (8)	89 (21)	68 (14)	54	26
Total	222 (20)	202 (18)	184 (38)	146 (25)	121	61

[a] Numbers of dropouts are indicated in parentheses.
From Rudinger and Schmitz-Scherzer (1976)

7. The Bonn, West Germany, Study

The Bonn Longitudinal Study of Aging was initiated by Dr. H. Thomae in 1965. The sample consisted of 220 men and women, born between 1890 and 1905, from different parts of West Germany. Each subject was examined at five different times during the period between 1965–1966 and 1972–1973 (Thomae, 1976). A control group of 61 new subjects was examined in 1972–1973. Table 9 shows the number of subjects tested at each period.

Since the goal of the study was to explore the factors involved in the marked variation among individuals apparent from cross-sectional studies of aging, a global approach, which relied heavily on interviews, was taken. At each measurement point, one three-hour interview was devoted to the assessment of present situation, one interview of two to four hours to that of the past (childhood, adolescence, young adulthood), and a third to assessment of the future outlook. Each interview was tape-recorded so that future analyses could be made in the light of new developments in theories about the psychological and social aspects of aging. In addition, standard psychological (WAIS; Raven Progressive Matrices), personality (Thematic Apperception Test; Rorschach; Riegel Scales), and psychomotor tests (choice and simple reaction time), and a brief physical examination to estimate health status were administered. The interviews focused on social conditions, social involvement, leisure activities, education, occupation, housing, life history, and outlook on the future.

The Bonn study, placing major emphasis on psychological and personality characteristics, highlights the marked individual variations in aging. More than 65 publications dealing with specific aspects of the data have already appeared (Thomae, 1976). The overall findings of the study point to the importance of interactions among health status, psychological competence, and social and economic conditions in determining patterns of aging. The richness of individual compensatory adaptations indicates that there are multiple pathways toward successful aging—a conclusion that can be drawn only from longitudinal observations.

STUDIES OF COMMUNITY POPULATIONS

The longitudinal studies described above have been conducted in relatively small selected populations. Other studies have used larger numbers of subjects selected from the total population of a community. The Framingham, Tecumseh, and Atomic Bomb Casualty Commission studies are examples.

1. The Framingham Study

In 1948, a prospective study designed to identify the relations of age, sex, family history, occupation, educational level, national origin, serum-lipid levels, smoking history, and physical activity to the development of CAD was initiated under the sponsorship of the United States Public Health Service. On July 1, 1949, the program was transferred to the newly established National Heart Institute.

The primary goal of the study was "the determination of factors influencing the development of heart disease." In order to meet this goal, it was recognized that repeated examinations of a large number of subjects from a community would be required. For this purpose two thirds of the 30- to 59-year-old population of Framingham, Massachusetts, were selected from published lists of all residents of Framingham over the age of 20 (Dawber et al., 1951). The process yielded 6507 individuals who were invited to participate in the study. Of this group, 4469, or 68.7% of the drawn sample, came to the study clinic for the initial examination, which was accomplished between 1948 and 1952. An additional group of 740 "volunteers" who were not selected by the formal sampling procedure were added to the original respondents. The total number of men and women tested at first visit was thus 5209 (Dawber et al., 1951; Gordon et al., 1959; Dawber et al., 1963; The Framingham Study, 1968–1974).

The study was designed to re-examine each subject every two years over a period of 20 years. At the eighth examination, 14 years after the first, 4678 subjects (89.8% of the original population) were alive; of these, 4030 (86.1% of those still alive and 77.4% of the original group) reported for examination.

By 1977, 3680 subjects were still alive and 1529 had died. Although the two-year test interval has not been strictly maintained since 1970, certain observations are continuing, with special emphasis on the factors involved in the development of cerebrovascular disease. The measured variables of major interest as risk factors for the development of CVD and for death are listed in Table 10. The data were analyzed longitudinally at the end of ten and 20 years, and numerous publications have appeared (The Framingham Study, 1974–1978).

The outstanding achievements of the study include the identification of significant risk factors for the development of CVD and the demonstration that they may be additive or multiplicative in their effects. The risk factors or predictors that have been identified are: cigarette smoking, elevated blood pressure, elevated serum cholesterol and low-density lipoproteins, low vital capacity, diabetes, and obesity. In addition, certain ECG abnormalities and x-ray evidence of cardiac enlargement are predictive (Kannel, 1978). These findings, which are convincing because of the longitudinal or prospective design of the study, have had a significant impact on public-health programs to reduce the incidence of CVD.

Table II.10. The Framingham Study

Major Independent Variables (Risk Factors)	Major Dependent Variables (End-Points)
Physical examination	Mortality
Blood pressure	Total
Height and weight	Coronary heart disease (CHD)
	Sudden death from CHD
History	Non-sudden death from CHD
Alcohol consumed	Cardiovascular, non-coronary
Cigarettes per day	Non-cardiovascular
Laboratory tests	Morbid events, vascular
Blood or serum	Heart
Glucose	CHD
Cholesterol	Myocardial infarction
Phospholipids	Angina pectoris
Hematocrit and hemoglobin	Congestive heart failure
Uric acid	Brain
Urinalysis	Cerebrovascular accident
Chest x-ray	Brain infarction
Vital capacity	Peripheral arterial
Electrocardiogram	Intermittent claudication

Compiled from data in The Framingham Study (1978)

2. The Tecumseh, Michigan, Community Health Study

The Tecumseh study, first planned in 1957, was designed as an ecologic investigation of an entire community, in contrast to studies based only on samples. The study was designed to identify the early origins of impaired health in order to detect precursors of overt illness at a time when preventive measures might be instituted (Epstein, 1960; Napier, 1962; Epstein et al., 1965; Montoye et al., 1965; Napier et al., 1970; Montoye, 1975; Montoye et al., 1978).

Although all residents of the town and its environs were contacted, approximately 80% or 8641 (4239 men, 4402 women) were actually tested between 1959 and 1960. The subjects ranged in age from birth to 70+ years (the 70+ group consisted of 127 men and 162 women, 3% of the total group). Approximately 45% of the subjects were younger than 20 years at the first testing.

In the years 1961 to 1965, the second cycle of examinations was conducted. A total of 9226 subjects or 82% of the population, including 2499 new residents, was tested.

A third cycle of examinations was conducted from February 1967 through June 1969. This cycle was limited to persons who had been examined at least once earlier and persons of all ages, whether previously examined or not, who resided in a 10% random sample of dwelling units. A number of relatives of subjects identified as having CAD or diabetes mellitus were also tested. Subjects tested in each of the three cycles totaled 4312.

Table 11 lists the tests administered in each cycle. Reports of cross-sectional analyses by age decades have been published for physical-activity levels, heart-rate response to exercise, oxygen uptake, ECG, proteinuria, and ventilatory response to exercise (Montoye, 1975); glucose tolerance (Montoye et al., 1977); forced vital capacity and other pulmonary-function tests (Higgins and Keller, 1973); and serum cholesterol and disease prevalence (Epstein et al., 1965). The testing program was terminated in 1970.

Table II.11. The Tecumseh Study: Tests Administered

	Cycle 1 1959–1960	Cycle 2 1961–1965	Cycle 3 1967–1969
Subjects			
Men	4239	4479	2857
Women	4402	4747	3155
Total	8641	9226	6012
New subjects		2499	
% of Tecumseh population tested	80	82	
History and physical exam	*	*	*
Anthropometry			
Height and weight	*	*	*
Skinfolds	*	*	*
Skeletal diameters	*	*	*
Laboratory tests			
Electrocardiogram			
Resting	*	*	*
Exercise step test		*	*
Treadmill exercise			*
Pulmonary function			
Vital capacity	*	*	*
$FEV^{1.0}$	*	*	*
Nitrogen washout			*
Roentogenographic studies			
Chest	*	*	*
Hand		*	
Cervical spine		*	
Fasting and one-hour glucose-tolerance test	*	*	*
Blood tests			
Hemoglobin	*	*	*
Blood type (11 groups)			*
Uric acid	*	*	*
Cholesterol	*	*	*
Triglycerides			*
Lipoprotein electrophoresis			*
Rheumatoid factors	*	*	*
Urinalysis	*	*	*
Skin sensitivity to tuberculin and histoplasmin (20% of population)		*	*
Activity questionnaire		*	*

From Montoye (1975)

Publications from the study have analyzed data by the cross-sectional method, with special emphasis on the role of physical activity in the maintenance of health. Longitudinal analyses of repeated observations on the same subjects have not been published.

3. The Atomic Bomb Casualty Commission Study

Almost immediately after the explosion of the atomic bombs over Hiroshima and Nagasaki and termination of hostilities, steps were taken by United States military

Table II.12. Atomic Bomb Casualty Commission—Hiroshima Study: Tests Administered to Clinical Subsample

On All Subjects at 2-Year Intervals
Height and weight
Skinfold thickness
Hematology
Hemaglobin, hematocrit, red-cell count, white-cell count, differential white count, sedimentation rate
Urinalysis, including microscopic examination
Stool examination for blood, ova, and parasites
Blood pressure
Chest x-ray
Questionnaire—history and present symptoms
Interview information on smoking, drinking, diet, occupation, and residential facts
On Part of the Sample at Varying Times
Chromosome studies (number and aberrations) in culture of lymphocytes
Cardiovascular disease
Grip strength
Anthropometric measurements
Vital capacity
12-lead electrocardiogram
Serum cholesterol, triglycerides, and uric acid
Blood clotting and lysis
Ocular fundus photography

Compiled from data in Hollingsworth et al. (1965), Finch and Beebe (1975), Belsky et al. (1973)

authorities to assess the immediate and long-term effects of exposure to radiation on longevity and the incidence of disease, especially cancer, among humans. Over a period of years the planning and supervision of the studies were transferred to the Atomic Bomb Casualty Commission (ABCC), whose members were appointed by the National Academy of Sciences of the United States and the Japanese National Institute of Health.

The primary focus of the studies was epidemiological, a comparison of morbidity and mortality from a variety of diseases in survivors of the explosions with morbidity and mortality in residents of Hiroshima and Nagasaki who were not exposed to radiation.

It was also recognized that steps should be taken to observe the development of any abnormalities induced by radiation exposure through repeated observations in the same subject over time—the longitudinal approach. Many radiobiologists at this time (about 1948–1952) were of the opinion that exposure to radiation simply "accelerated normal aging;" to test the hypothesis, serial observations in both the exposed and the non-exposed were necessary.

In 1958 a sample of about 20,000 subjects was drawn by statistical techniques from a total population of 110,000 identified as residents of Hiroshima at the time the bomb was dropped. The 20,000 were about equally divided among four groups of about 5000 each who had been within 2000, 2000 to 2500, and 2500 to 10,000 meters of the epicenter, or had not been exposed to radiation because they had been out of the city when the bomb was dropped. Observations on the subjects in the non-exposed group provided control data.

The design of the study called for detailed medical examinations, with some

laboratory tests to be conducted on each of the 20,000 subjects at two-year intervals. Although the task proved greater than the resources, a great many serial examinations were completed. Since the primary interest of the study was to identify the long-term effects of exposure to radiation, analysis of age effects was not given a high priority. In addition to a standard medical history and physical examination, height, weight, blood pressure, chest x-ray, blood morphology, hemoglobin, and routine urine examinations were made in practically all subjects (Tab. 12). Additional tests, including extensive anthropometry, skinfold thickness, grip strength, vital capacity, 12-lead ECG, serum cholesterol, triglycerides, and uric-acid levels in the blood were conducted in subpopulations over varying periods of time. Cross-sectional analyses were used, but no publications have presented results based on longitudinal analyses.

In April 1975 responsibility for all studies was transferred to a newly established Japanese Radiation Effects Research Foundation, under which studies of the long-term effects of exposure to ionizing radiation are being continued (Atomic Bomb Casualty Commission, 1978).

Most of the publications from the ABCC study are concerned with determining the effect of exposure to various levels of radiation on the incidence of disease, especially cancer. In general, exposure to non-lethal doses of radiation did not seem to have any significant long-term effects. Radiation injuries were primarily confined to the period immediately following acute exposure, and the incidence of symptoms (epilation, bleeding, and oropharyngeal lesions) increased almost linearly from 5%–10% among those exposed to a total dose of 50 rad to 50%–80% among those exposed to about 300 rad, beyond which the proportion leveled off (Atomic Bomb Casualty Commission, 1978).

Hollingsworth et al. (1965) attempted to devise an index of physiologic age based on measurements of a number of physiological variables in 437 non-exposed males and females, aged from 10 to 70 years, from the ABCC Adult Health Study. Scores on nine tests—skin elasticity, systolic blood pressure, pulmonary vital capacity, hand-grip strength, visual reaction time, vibratory perception at the ankle (120/sec), visual acuity (Snellen), auditory threshold (decibels at 4000 cycles/sec), and serum cholesterol—were combined in a multiple regression equation to provide a "physiological age" score for each individual. When a value for "physiological age" was derived, it was highly correlated with chronological age. The observations, however, were not analyzed to determine whether subjects whose physiologic age was lower than their chronological age had lived longer. Such a test for the validity of an index of physiological age is essential; but until follow-up observations have been made over a period during which a substantial number of the subjects have died, no definitive answer can be given.

Examinations of mortality data on a large sample of Japanese over the period from 1950 to 1972 provided no support for the hypothesis that exposure to ionizing radiation accelerates aging. The effects appear to be the result of specific radiation-induced diseases, especially neoplasms (Finch and Beebe, 1975).

Dock and Fukushima (1978) analyzed observations of blood pressure in 13,814 Japanese subjects who were participants in the ABCC Adult Health Study. Blood pressures were measured at two-year intervals between 1958 and 1972. At the seventh examination, in 1970–1972, 8707 or 72% of the 12,123 subjects still in the study were examined. In subjects younger than 60 years, there was a small but consistent rise in average values for both systolic and diastolic blood pressure with increasing age over the period. Subjects in a recent cycle exhibited pressures about the same as or slightly

lower than those of subjects who had been the same age a decade or more earlier. Subjects aged 60+ at the time of the initial test failed to show any further increase in pressure during the subsequent years. Very few "mild" hypertensives progressed into the "severe" category during the period of study. Initial pressure and age were the primary predictors for the development of hypertension. Subjects who had shown a transient rise in blood pressure at their first visit had a higher risk of an increase in blood pressure over the following decade than subjects with stable values during the first visit.

STUDIES OF SPECIFIC VARIABLES

1. Intellectual Functions

A number of studies have used the longitudinal method to investigate age changes in specific domains. Owens (1966) reported on the serial analysis of Army Alpha test scores for intelligence of 96 men tested in 1961 ($\bar{x}$ age = 61 yr) who had originally been tested as entering freshmen at Iowa State University in 1919. They represented survivors of a group of 127 subjects who had been retested in 1949–1950 at a mean age of 50 (Owens, 1953). Of the 31 subjects lost between 1949–1950 and 1961, 13 had died, five were disabled, five could not be located, and eight refused to participate. The important finding of the study was that within individuals there was little change in test scores over the ten-year interval from 1950 to 1960. The previous report (Owens, 1953) had shown increments in verbal ability and total score over the interval between 1919 and 1950 (age span 20–50 yr), although numerical ability showed a slight decrement. This study was the first to raise serious doubts about the presumed decline in mental abilities with advancing age that had been inferred from previous cross-sectional studies (Jones and Conrad, 1933).

In 1921–1922, a group of 1528 intellectually gifted children, whose age range was from three to 19 years, was selected by means of intelligence tests. The study, organized by L.M. Terman, is known as the Terman-Stanford study of gifted children. The subjects ($\bar{x}$ I.Q. = 151, range 140–200) have been followed since 1921 by means of field-worker interviews, questionnaires, tests, and personal correspondence. Special tests of intellectual function were administered to 954 subjects ($\bar{x}$ age = 29.5 yr) in 1939–1940, and to 768 subjects ($\bar{x}$ age = 41.5 yr) in 1952. An analysis by Bayley and Oden (1955) of changes in test scores over the 12-year interval showed that, in general, scores on the mental tests increased in individual subjects between the ages of 30 and 40 years.

Schaie and his co-workers have examined the changes in intellectual performance with age. The five subtests of the SRA Primary Mental Abilities (Thurstone and Thurstone, 1949) and Schaie's test of Behavioral Rigidity were administered to subjects drawn on three occasions (1956, 1963, and 1970) from approximately 18,000 members of a prepaid medical plan operating in the Pacific Northwest. In 1956, 25 men and 25 women in each five-year interval from 21 to 70 years of age were tested. In 1963, 302 of the original 500 subjects were retested; 161 were tested for a third time in 1970. In addition, 960 subjects were tested for the first time in 1963; of these, 409 were retested in 1970. Another 701 men and women were tested for the first time in 1970. As a result, it was possible to measure seven- and 14-year longitudinal changes,

and to estimate mean changes by comparing independent samples from the same birth cohorts at the seven- and 14-year intervals. Schaie and Labouvie-Vief (1974) concluded that much of the apparent age decline was in reality due to birth-cohort differences and that aging did not result in an inevitable decline in all intellectual functions.

2. Physiological Variables

Blood pressure. Jenss (1934) examined in detail the rate of change of systolic blood pressure with age in individual male subjects. The data were obtained from annual physical examinations of 1139 United States Army officers (age range = 27-54 yr) between 1916 and 1930. Each subject provided at least seven observations ($\bar{x}$ = 9.4 observations over $\bar{x}$ period of 12.3 yr, range = 7-14 yr). The longitudinal analysis showed that age differences in systolic blood pressure derived from cross-sectional data were not representative of all the officers. Some individuals showed an appreciable decline in pressure, others a corresponding rise, during the period of observation. Regression toward the mean was observed: Officers with an initial reading considerably above the average tended to show a decrease in systolic pressure with age, those with a low initial pressure an increase. The inverse relation between the initial level and the trend of systolic pressure was more marked in the young than in the old officers.

Engel and Malmstrom (1967) analyzed blood-pressure measurements made annually over a period of 20 years on 242 male employees of the Travelers Insurance Company. Although a single linear regression of blood pressure on age could be fit to the observations on most of the subjects, 56 were identified in whom two straight lines of different slopes were needed to describe the data. The ability to detect a change in slope or any form of non-linearity obviously requires multiple longitudinal observations over a substantial number of years.

Exercise. In a study by Robinson et al. (1975), the physiological adjustments to both aerobic (5.6 km/hr, at 9% grade) and maximal treadmill work, which had first been determined when the subjects were college students, aged from 18 to 22 years, were compared with measurements made in 20 of the same subjects at ages 40 to 44 and again at ages 49 to 53. In the aerobic walk, oxygen consumption increased in proportion to the gain in body weight, but efficiency did not change with age; the amount of oxygen consumed per unit of work remained the same. The men who had gained the most weight showed the greatest elevations of heart rate and blood lactate after exercise, with a significant decrease in the efficiency of lung ventilation.

The most pronounced changes with age occurred in metabolic, respiratory, and circulatory adjustments to maximal or exhausting work. Over the 30 years of the study, maximum oxygen consumption declined between 20% and 30% in individual subjects. The most important finding, however, was that eight of the men showed an average increase of 11% in maximum oxygen uptake between the ages of 40–44 and 49–53 years. This increase in physical fitness was associated with increased participation in vigorous activities and cessation of smoking.

Dill et al. (1967) assessed the physiological state of 16 runners on two occasions over a span of 20 years. Many of the subjects had been Olympic contenders, a few world champions; they displayed unusual physical fitness at the time of their first testing. In addition to a clinical assessment including chest x-rays, ECG, urinalysis, and

measurement of serum cholesterol, pulmonary-function tests were carried out. Observations made with the subjects in the basal state included oxygen consumption, CO_2 production, respiratory rate and minute volume, heart rate, and blood pressure. Arterial blood samples were analyzed for hemoglobin oxygen saturation, pCO_2, pO_2, and CO_2 combining power. Physiological responses to grades of exercise performed on a treadmill were measured. Although complete observations were not obtained on all subjects, age trends for the group as well as for the individual subjects could be identified. The major finding was that age differences based on average values for the group did not predict age changes found in individual subjects tested after an interval of 20 years. Although maximum oxygen uptake decreased in all the subjects, the amount of the decrease varied widely among subjects. Despite the absence of statistically significant results, the authors concluded that regular strenuous exercise and the absence of cigarette smoking seemed to be conducive to a high level of physical fitness.

Asmussen et al. (1975) re-examined 19 men ($\bar{x}$ age = 60.7 yr) and six women ($\bar{x}$ age = 63.2 yr) who had been tested first as students of physical education ($\bar{x}$ age: men, 23.9; women, 23.5 yr) and later at mean ages 48.7 (men) and 51.3 years (women). Measurements made under resting rather than basal conditions included blood pressure, heart rate, O_2 uptake and CO_2 production, vital capacity, residual air, hand-grip strength, and reaction time to light and sound. Exercise testing (Krogh bicycle ergometer) at 617 kpm/min (men) and 411 kpm/min (women) was used to determine O_2 uptake. Average curves showed significant age decrements in vital capacity, hand-grip strength, speed of reaction, and maximum oxygen uptake during exercise. Systolic blood pressure increased with age. Decrements seemed to be greater between ages 48 and 62 than between 23 and 48. The authors concluded that the changes in physiological functions they had observed over a period of 40 years (at ages 20–60) seemed to be identical with the results of most cross-sectional studies of the same functions.

Åstrand et al. (1973) retested 35 female and 31 male physical-education students (aged 20–33 yr at initial testing) after an interval of 20 years. The subjects performed submaximal and maximal exercise on a bicycle ergometer. Although at the second testing maximum oxygen uptake had declined by approximately 20%, wide individual differences were found. Average values for maximum oxygen uptake were, however, in good agreement with the findings of other cross-sectional and longitudinal studies.

Dehn and Bruce (1972) measured maximal oxygen uptake during a multistage treadmill test in 86 healthy men between 40 and 72 years of age. In 40 of the subjects similar tests had been made two to three years earlier. A cross-sectional analysis revealed an average annual decrement in maximum oxygen uptake of 0.28 ml/min·kg. Combined data from 17 cross-sectional studies found in the literature showed an average annual decrement of 0.40 ml/min·kg. Longitudinal analysis of the repeated observations on 40 subjects of the present study revealed a significantly greater annual decrement of 0.94 ml/min·kg, which compared remarkably well with longitudinal results previously reported by Dill et al. (1967).

Although both cross-sectional and longitudinal analysis indicate that on the average maximum oxygen uptake tends to fall with age, longitudinal studies show that the downward trend may be reversed in middle-aged subjects. It is assumed that such changes in life style as elimination of cigarette smoking and the introduction of regular regimens of exercise contribute to this reversal.

SUMMARY

This brief review of the major longitudinal studies that have been or are being conducted on adults illustrates the great diversity in design, subject selection, and tests administered. This diversity is a source of both strength and weakness. The strength lies in the broad spectrum of tests that have been used. The weakness is the limited possibility for comparisons between different types of performance within the same subject. Few studies have included a wide range of both psychological and physiological tests in the same subjects.

Table 13, which summarizes the major features of selected longitudinal studies of adults, shows the diversity in their design and execution and emphasizes the fact that the ideal longitudinal study is yet to be designed.

It is inevitable that many serial observations that have been collected have never been analyzed longitudinally with respect to aging. This omission seems often to have been due to the emergence of unanticipated methodologic complexities in the longitudinal analysis of data; not uncommonly, it has resulted from loss of critical personnel or fiscal resources. Although several of the studies enumerated in Table 13 had never had as their primary goal an assessment of the age changes for their own sake, their data bases offer the potential for such analysis.

The criteria for subject selection have varied widely. In most studies the number of subjects is relatively small; groups are often highly selected and usually male. Women are grossly underrepresented, and no studies have included blacks or other ethnic groups as identifiable subsets.

Since longitudinal studies have been initiated by groups of investigators with different interests and goals, communication among investigators has often been minimal. In order to improve communication among investigators in longitudinal studies, a series of six conferences held between 1972 and 1975 (Rose, 1976) brought together representatives from eight longitudinal studies: Baltimore Longitudinal Study of Aging; Normative Aging Study; The Framingham Study; the Duke University Studies of Human Aging; the 1000-Aviator Study; the Tecumseh, Michigan, Community Health Study; the CVD Project at the University of Minnesota; and the Kaiser Permanente Foundation Study, Oakland, California (not reviewed here because of the absence of documentation.)

The meetings provided a forum for the interchange of information and discussion of problems associated with the operation of longitudinal studies. The question of pooling data for specific tests from a number of studies was explored. Data for height, weight, blood pressure, cholesterol, and vital capacity obtained from five longitudinal studies (Duke, Tecumseh, Baltimore Longitudinal Study of Aging, Minnesota, and Normative Aging Study) were compared (Garvey, 1973). The results showed that pooling of original observations from different studies was impractical because of systematic differences in the selection of population and in methods of measurement. Although direct pooling of data may not be feasible, the results of longitudinal analyses from different studies can be compared. Age trends found in a number of studies are apt to support more valid generalizations than those found only in a single study. On the other hand, results found in some populations but not in others may provide important epidemiological clues to demographic, genetic, or environmental variables that influence the responses to aging.

Table II.13. Selected Longitudinal Studies of Adults

Study	Began	Ended	Nature of Sample	N	Sex & Ages at Entry	Test Interval	Test Period	N Repeat Cycles	Variables Measured[a]	Health Criteria	
										Admission[b]	Analysis[c]
Minnesota	1947	1977	Professional and business men	281	M 45-54	Annual	1 day	?	Anthropometry Behavior and Personality	Yes	Yes
Duke I	1955	1976	Community Residents	260	M & F 60-94	2 yr	2 days	11	Psychiatric Psychology Physiology Anthropometry Blood chemistry Social history	Yes	Yes
Duke II	1968	1976	Community residents selected from register of health-insurance plan	502	M & F 45-69	2 yr	1 day	4	Psychology Social History Personality	No	Yes
Normative Aging	1963	Continuing	Community residents in Boston area	2032	M 25-75	5 yr	3 half days over 5-year period	3	Biochemistry Special senses Anthropometry Psychology Sociology	Yes	Yes
1000-Aviator	1940	1970	Cadets and officers in flight training	1056	M 20-30	Irregular	—	4	Physiology Psychomotor Psychology	Yes (rigorous)	Yes
NIMH	1955	1967	Community residents in Philadelphia area	47	M 65-91	5 yr	2 wks	3	Psychiatric Interview Cerebral physiology Psychological tests Social history	Yes	Yes

Table II.13. Selected Longitudinal Studies of Adults—(*Cont'd.*)

Study	Began	Ended	Nature of Sample	N	Sex & Ages at Entry	Test Interval	Test Period	N Repeat Cycles	Variables Measured[a]	Health Criteria	
										Admission[b]	Analysis[c]
Basel	1955	1965	Community-residing CIBA employees and retirees	121	M 8-85 (Most 26-56)	1-2 yr	1 day	2 to 5	Anthropometry Physiology Sensory tests P.W.V.	No	No
Bonn	1965	1976-77	Community residents in W. Germany	220	M & F 60-75	2-4 yr	1 week	5	2- to 4-hr interviews Intelligence Personality	Yes	No
Framingham	1948	Continuing	Community residents	5209	M & F 30-59	2 yr	1 day	10	Blood chemistry end points—CV disease	No	Yes
Tecumseh	1959	1969	Total community	8641	M & F Birth to 70+ (45% under age 20)	3 yr	—	3	Anthropometry Physiology Blood chemistry Activity questionnaire	No	Yes
ABCC Adult Health	1958	1972	Non-exposed residents of Hiroshima	12,123	M & F birth to 70+	2 yr	½ day	7	Anthropometry Physiology Blood chemistry	No	No
BLSA	1958	Continuing	Community-residing males[d]	1142	M[d] 17-96	1-2 yr	2 ½ days	21 (as of 6/81)	See Chapter IV	No	Yes

[a] All studies in table recorded histories and performed physical examinations.
[b] Were health criteria used to select subjects for admission to the study?
[c] Were health criteria used to determine whether individuals' values were used in analysis?
[d] Women have been recruited to the study since 1978.